

Surge Voltage Suppression in Residential Power Circuits

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Significance:

Part 4 – Propagation and coupling of surges

Part 7 – Mitigation techniques

Part 8 – Coordination of cascaded SPDs

Laboratory tests on the effect of distance for coordination between a surge-protective device (SPD) at the service entrance and an SPD at the end of a branch circuit.

The service entrance SPD, 1960-1970 vintage, consisted of a silicon carbide disc with a series gap.

The branch circuit SPD consisted of a simple MOV disc incorporated in a modified plug-and-receptacle combination, probably the first attempt at packaging an MOV for residential surge protection.

Tests were performed with a simple generator capable of delivering up to 8 kV peak open-circuit voltage of 2/60 : s waveform and 2 kA peak short-circuit current of 30/50 : s waveform. These values – dating back to pre-IEEE 587 consensus waveforms – were at the time deemed to represent a severe surge associated with a lightning flash to the power system, outside of the residence.

One objective of the tests was to determine the values of surge current and distance between SPDs that produced the threshold from no sparkover of the service entrance SPD (maximum stress on the MOV) to sparkover, thus limiting the stress on the MOV. This was one of the first illustrations of what became a series of experimental and theoretical studies of the “cascade coordination” concept.

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<small>ORIGINATING COMPONENT</small> Electronic Power Conditioning and Control Laboratory		<small>CORPORATE RESEARCH AND DEVELOPMENT SCHENECTADY, N. Y.</small>
<small>SUMMARY</small> Tests performed on a representative residential wiring system with a Home Lightning Protector (HLP) and a Voltage Spike Protector (VSP) installed on the service box and an outlet, respectively, indicate good coordination between the characteristics of the two devices. For surge of relatively small amplitude, the VSP performs all of the voltage clamping functions. As the energy (current) of the surge increases, a point is reached where the HLP spark-over voltage is reached, and this device takes over the function of diverting the surge energy while the VSP keeps the voltage clamped at low levels. The current for which this transfer takes place depends on the distance between the two devices. For practical situations, enough distance (wiring length) will exist to limit the duty imposed on the VSP to acceptable levels, giving the HLP an opportunity to divert high energy surges.		
<small>KEY WORDS</small> transients, spikes, lightning, arrestors, varistors, GE-MOV		

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SURGE VOLTAGE SUPPRESSION
IN RESIDENTIAL POWER CIRCUITS

- F.D. Martzloff -

I. INTRODUCTION

Surge voltages occurring in residential power circuits have two origins: external surges, produced by power system switching operation or by lightning, and internal surges produced by switching of appliances in the home. The voltage levels of these surges are sufficient to cause failure of sensitive electronic appliances, and some of the higher surges can even fail the more rugged electromechanical devices (clocks, motors and heaters)^{1,2}.

For many years, the General Electric Company has offered a secondary surge arrester under the name of "Home Lightning Protector" (HLP), which is very effective in protecting non-electronic devices against high energy, high voltage surges associated with lightning or power system switching. However, the protective level of this arrester, consistent with the limitations imposed by the design of such a device, is still too high for sensitive electronic devices. Furthermore, its installation requires a competent electrician.

A new suppressor has been developed and introduced by the Wiring Device Department under the name "Voltage Spike Protector" (VSP); this device incorporates a GE-MOV® varistor in a plug-in device allowing purchase and easy installation by the user. The protective level of this device is substantially lower (that is, better protection is provided) than the HLP, so that protection of sensitive electronic appliances is now possible. However, the energy handling capability of this suppressor is lower than that of the HLP, so that large currents associated with lightning strikes cannot be handled by the device.

The availability of these two different types of suppressors now makes it possible to obtain a coordinated protection of all the appliances in a home. Installation of the HLP at the service entrance will deal with the larger surges, while the VSP installed at a wall receptacle will protect the more sensitive devices. For the lower surges, the VSP will clamp the voltage to a low level. For the higher surges, the VSP will first attempt to absorb all the surge current, but the voltage developed across the varistor plus the voltage drop in the wiring between the receptacle where the VSP is installed and the

service box where the HLP is installed will reach the sparkover voltage of the HLP. The HLP then takes over, diverting the high current surge from the VSP, so that no excessive energy is applied to the latter.

This report describes how this coordination takes place, based on simulated surges in a representative wiring system. The levels of voltage and current in these tests show when the HLP and VSP respectively assume all of the protective function, and where the transfer takes place, depending on the distance between the VSP in an outlet and the service box where the HLP is installed.

II. THE HOME LIGHTNING PROTECTOR

The Home Lightning Protector (HLP), is produced by the Distribution Transformer Business Department. It is a surge arrester of the valve and series gap type (Fig. 1). Earlier designs involved lead oxide pellets, with the oxide pellet acting as a nonlinear resistor and the multiple contact points between the pellets as a multiple gap. A more recent design uses a Thyrite® disc in series with a low voltage gap.

This UL-listed arrester is rated for lightning surge duty, and is described in the GE Handbook as having a sparkover of 2 kV crest under a 10 kV/μs impulse with discharge voltages of 1, 1.2 and 1.4 kV respectively at 1500, 5000 and 10,000 A for a 10 x 20 μs current wave (see Appendix I).



Figure 1. Home Lightning Protector

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As any gap-type arrester will, the HLP has a volt-time characteristic exhibiting some increase in the sparkover voltage as the rate of rise of the impinging surge increases. Typical sparkover voltages for the sample tested under the particular waveform used here were in the order of 2000 V or less. This represents an effective clamping to protect electromechanical appliances, heaters, etc. However, sensitive electronic appliances may well have failure levels below 2000 V. This is recognized in the box label which describes the HLP as a protector for "home and farm non-electronic equipment, wiring appliances and water heaters".

Thus, while the HLP offers reliable protection for non-electronic appliances and a respectable energy handling capability, a device with a lower voltage clamping characteristic is required to protect sensitive electronics. This need is now met through the Voltage Spike Protector, described in the next section.

III. THE VOLTAGE SPIKE PROTECTOR

The heart of this device is a GE-MOV® varistor, connected line-to-line in a combination plug-socket (Fig. 2). This package, developed and produced by the Wiring Devices Department, makes it convenient for the user to install the protector at any outlet in the house, and the socket end allows the user to plug the protected appliance directly into the protector. In fact, protection is afforded to devices in all other wall outlets (to a varying degree, depending on the branch circuit configuration) and it is not mandatory to plug the appliance into the suppressor (it is a shunt, not a series device). One of the reasons for the socket end is just a convenience, so as not to lose the use of a receptacle or require a cube tap.

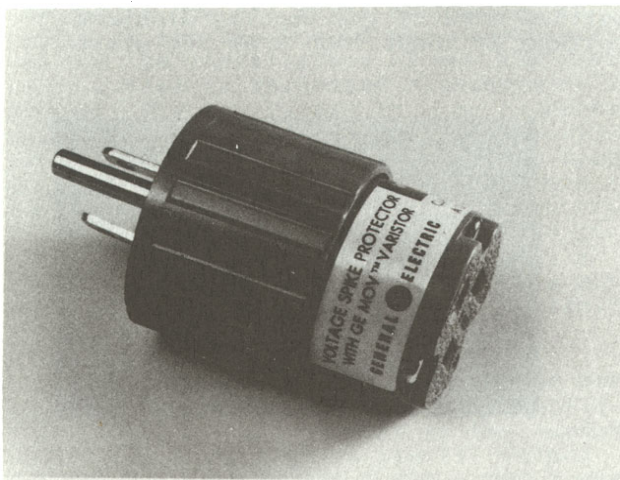


Figure 2. Voltage Spike Protector

In addition to the varistor, a non-resettable, one-shot thermal protection is inserted in series with the varistor, as insurance against thermal runaway of the varistor in case of excessive environmental conditions.

The protective characteristics of the varistor are such that a 15 A surge, typical of large internally-generated surges, will limit the voltage across the suppressor to 500 V, as opposed to values exceeding 2000 V which have been recorded during monitoring of houses known to contain a switching device producing such surges¹. For large current values such as those associated with "lightning remnants", i.e. surge entering the house when a lightning stroke occurs near the house (but not a direct stroke), one can expect currents in the order of 1000 to 2000 A. These would produce a voltage of 800 to 1000 V across the varistor. However, as we will see, the presence of an HLP device at the service box, ahead of the varistor, will limit the current flowing toward the varistor to a lower value, by diverting the current through the HLP because of the additional drop in the wire which raises the voltage across the HLP to its sparkover voltage.

IV. TEST CIRCUIT

The test circuit (Fig. 3) consisted of a terminal board from which two lines, one 25 ft. (7.5 m) and the other 100 ft. (30 m) long were strung in the test area. A short 10 ft. (3 m) line simulated the service drop. All of these were made of 3-conductor non-metallic sheath wire (Etcoflex type NM) #12 AWG. The neutral and the ground wire of the three lines were connected together at the terminal board, and thence to the reference ground of the test circuit.

All surge currents were applied between the line conductor (black) at the end of the service drop and the reference ground. These impulses were obtained from a 5 μ F capacitor, charged at a suitable voltage, and discharged into the wiring system by an ignitron switch. Figure 4 shows the connections and parameters of the surge generator circuit. The resultant open-circuit voltage waveform, a unidirectional wave of 1 μ s rise time x 50 μ s to 1/2 value time, corresponds to the standard test wave in utility systems. It is a much more severe test than the recommended TCL waveshape^{2,4} and as such provides very conservative results. Figure 5 shows typical open-circuit voltage and short-circuit current waveforms. Voltages were recorded by a Tektronix 7633 storage oscilloscope through a P6015 attenuator probe (1000:1); currents by a Tektronix 7633 oscilloscope through a current probe P6042 with a CT-5 1000:1 current transformer. Thus, the calibrations displayed on the oscillogram are to be multiplied by 1000 for the voltage,

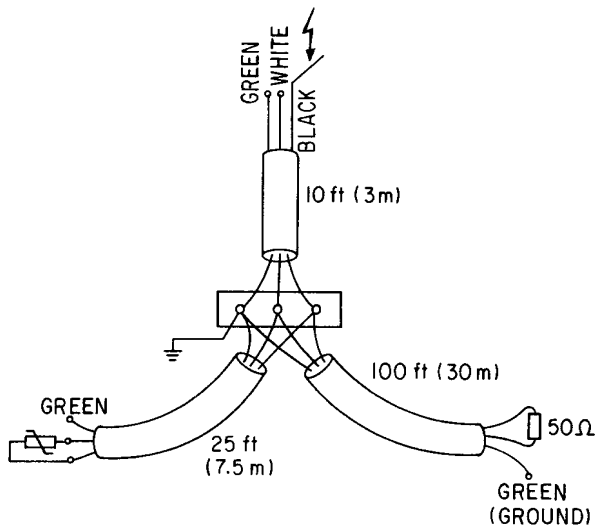


Figure 3. Test Circuit

while the current traces show the 50 mV setting corresponding to the rated output of the current probe, with the ampere per division shown corresponding to the current transformer ratio and current probe input setting for a direct reading. Sweep rate is also shown on the oscillograms, at 10 μ s/div. for all the tests.

V. TEST RESULTS

Several test conditions were investigated, with the varistor at the end of the short line or at the end of the long line. The HLP and VSP responses were established by connecting them one at a time, in addition to establishing the open-circuit voltage and short-circuit current for each

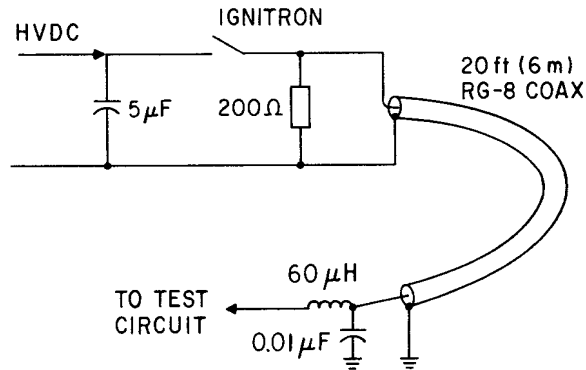
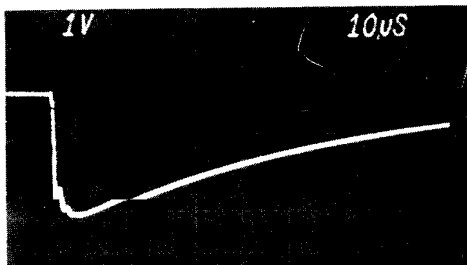


Figure 4. Pulse Generator Circuit

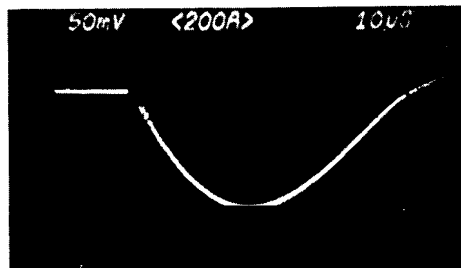
condition. The results will be discussed with reference to specific sets of oscillograms showing voltages and currents in various parts of the circuit, each time for the same setting of the surge generator.

1. HLP AND VSP RESPONSE

Figure 5a shows a 3000 V open-circuit voltage surge at the service box, with neither suppressor connected. Figure 5b shows the corresponding 600 A short-circuit current for a jumper connected at the service box. Figure 6a shows the voltage across the HLP when subjected to the surge defined by Figures 5a and 5b. Note that the sparkover voltage reaches 2200 V with several oscillations before the voltage settles down to the impulse discharge voltage at about 1000 V at its start.

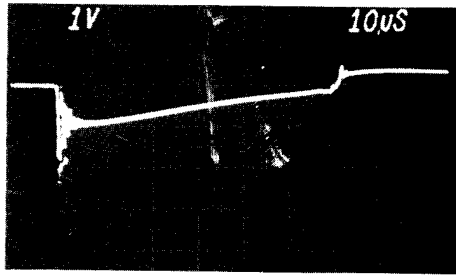


(a)

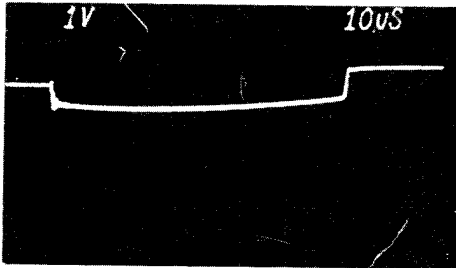


(b)

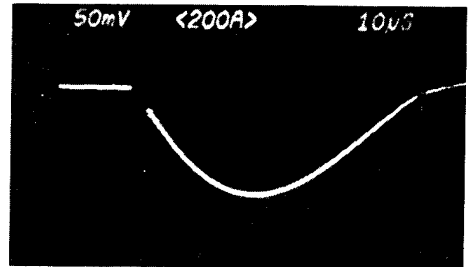
Figure 5
Open Circuit Voltage and Short-Circuit Current
(without any protector)



(a)



(b)



(c)

Figure 6
Response of HLP & VSP

Figures 6b and 6c show respectively the voltage and current across the varistor. Note that the maximum voltage is 600 V, for a 550 A current on the varistor. (The current in the varistor is lower than the available short-circuit current because of the reduced available voltage since the varistor holds off 600.

2. PROPAGATION OF SURGES

Figure 7 shows several oscillograms indicating how the surge propagates in the wiring in the absence of any suppressor, and how the installation of one VSP device at an outlet is reflected elsewhere in the system. Figures 7a and 7b show respectively the open-circuit voltage and short-circuit current at the service box. At the open-ended 25 ft. (7.5 m) line, the voltage is substantially the same as at the box (Fig. 7c). However, at the end of the 100 ft. (30 m) line with a 50 Ω termination, a significant decrease of the slope is noticeable, while the crest remains practically unchanged (Fig. 7d).

In Figures 7e-g, a VSP varistor has been added at the end of the 25 ft (7.5 m) line. Voltage and current at the varistor are shown in Figures 7e and 7f, with a maximum voltage of 500 V for a 200 A surge. Meanwhile, the voltage at the box is limited to 750 V, an appreciable reduction from the 1500 V that would exist without the remote

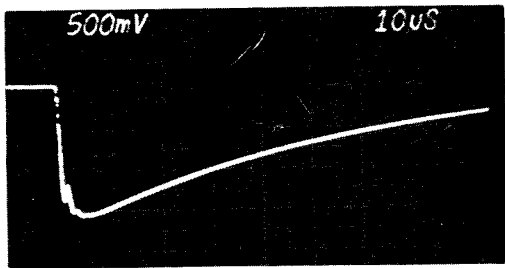
VSP under this surge condition (Fig. 7g).

3. TRANSFER OF SURGES

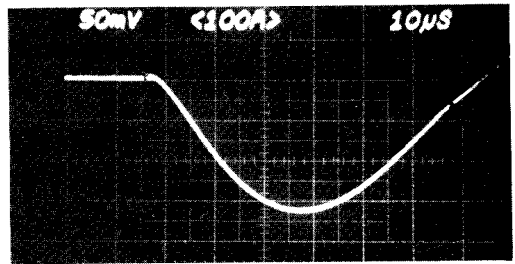
With the voltage limiting at the box provided by the installation of a VSP, even at a remote outlet (Fig. 7g), an HLP connected at the service box cannot reach its sparkover voltage until substantial surge currents are involved. For a short distance between the service box and the VSP, a larger current will be required than for a greater distance. The value of the current required to reach sparkover as a function of the distance is therefore of interest.

For a distance of 25 ft. (7.5 m), the threshold condition where sparkover of the HLP just occurs is depicted in Figure 8. In Figures 8a and 8b, the open-circuit voltage and short-circuit current are shown for this threshold setting of the generator. Inspection of the oscillograms shows an open-circuit voltage of 8.1 kV and a short-circuit current of 1.9 kA, hence a calculated source impedance of 4.2 Ω .* This low value of the source impedance (compared

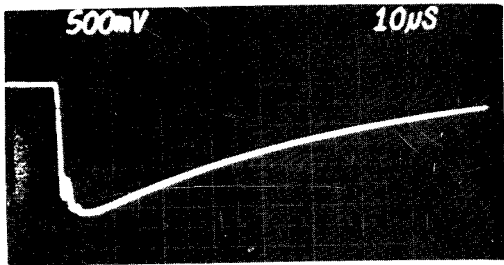
* This is only a crude approximation since the current waveform does not match the voltage waveform. Therefore, the circuit impedance is not a pure resistance or characteristic impedance.



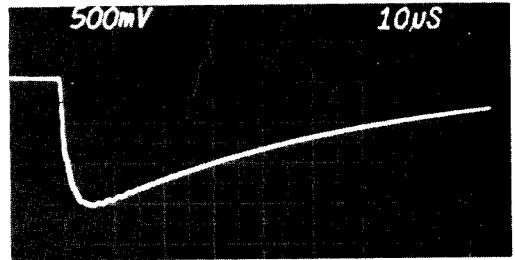
(a) open-circuit voltage - at box



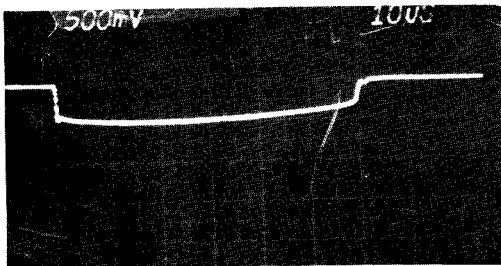
(b) short-circuit current



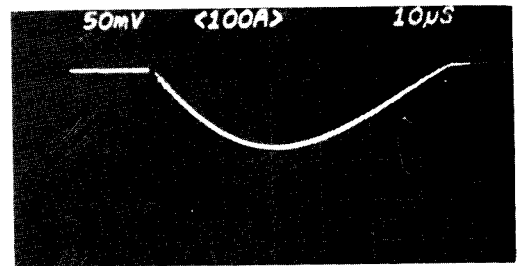
(c) open-circuit voltage - 25 ft. (7.5m)



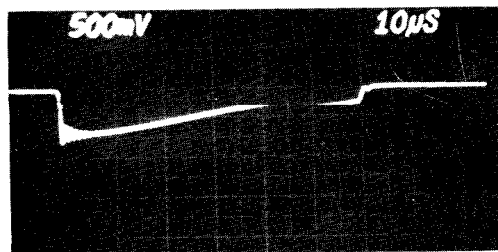
(d) open-circuit voltage - 100 ft. (100m)



(e) voltage at VSP - 25 ft. (7.5m)



(f) current in VSP - 25 ft. (7.5m)

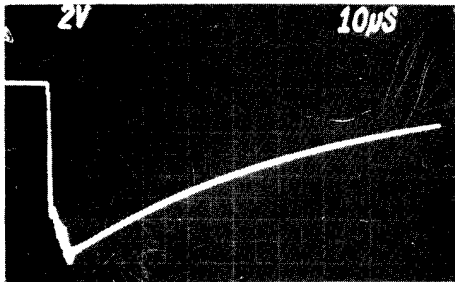


(g) voltage at box with VSP @ 25 ft. (7.5m)

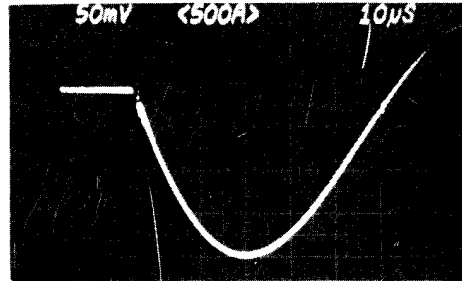
Figure 7
Propagation of Surges

to proposed values^{2,3}) provides a very conservative evaluation of the system performance. For the same setting as Figures 8a and 8b, the oscillograms of Figures 8c and 8d show the case where the HLP has sparked over, as indicated by its voltage (8c) and current (8d) traces. In Figures 8e and 8f, the traces show the voltage (8e) and current (8f) in the VSP for a case where the HLP did not spark over (due to the scatter of spark-over or a slight difference in the output of the surge generator). This case represents the most severe duty to which the VSP would be exposed, for a distance of 25 ft. (7.5m), and in reality is already likely to be an actual lightning stroke on the power system, rather than just a "lightning remnant" associated with a remote or indirect stroke. Figure 8f indicates a crest current of 1200 A in the varistor, which just exceeds the published surge rating of the varistor,

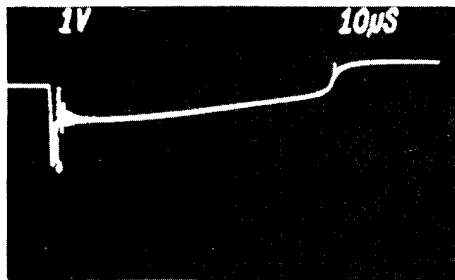
however, as an isolated occurrence, this current level has been found acceptable during laboratory tests. As stated above, this level of current would be reached only for direct strokes, and for a VSP connected fairly close to the service box. In a case where there would be no HLP installed at the box, but only the VSP installed at an outlet, the voltage rise in the wiring and the meter coils would most likely result in a flashover of the system, which would then divert the excessive energy away from the VSP, just as the HLP did in the test. Of course, this diversion may take place in an undesirable manner, which is precisely what the HLP is supposed to eliminate when installed. On the other hand, the sale literature for the VSP also specifically excludes direct lightning strokes from the protective ability of the VSP.



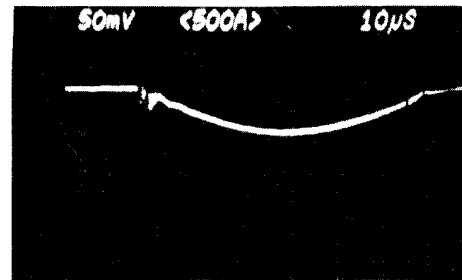
(a) open-circuit voltage



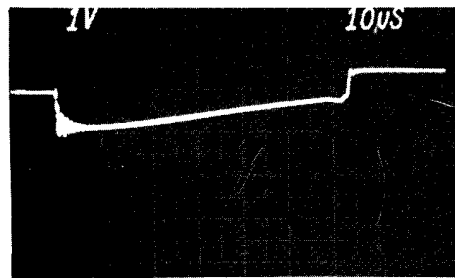
(b) short-circuit current



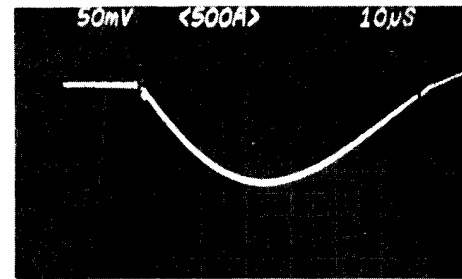
(c) voltage at HLP when HLP does sparkover - VSP at 25 ft. (7.5m)



(d) current in HLP after sparkover - VSP at 25 ft. (7.5m)



(e) voltage at VSP when HLP does not sparkover - VSP at 25 ft. (7.5m)

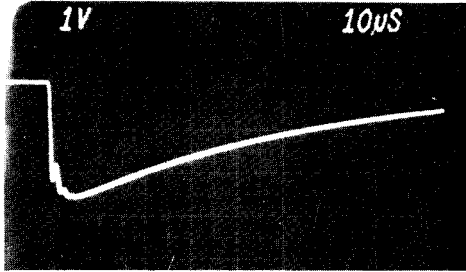


(f) current in VSP when HLP does not sparkover - VSP at 25 ft. (7.5m)

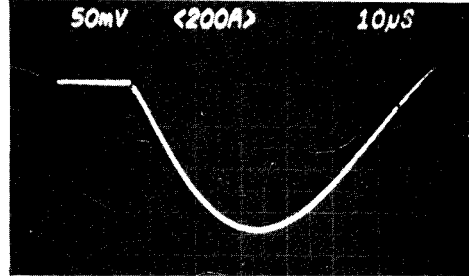
Figure 8
Transfer of Surge Conduction

For greater distances between the VSP and the service box, the surge transfer will occur at lower current. For instance, with 100 ft. (30m), the oscillograms of Figure 9 document the transfer of the surge to the HLP at much lower current levels. Open-circuit voltage and short-circuit current are indicated in Figures 9a and 9b as previously. With the VSP at 25 ft., only the VSP carries the surge as indicated in

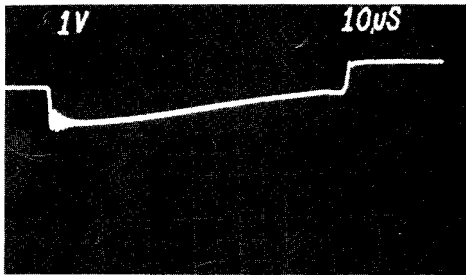
Figures 9c and 9d. However, with the VSP removed 100 ft. (30m) away from the HLP, the latter takes over for this lower available current (700 A) and relieves most of the surge from the VSP, as indicated in Figures 9e through 9h. The current flowing in the VSP is now only 125 A (Fig. 9f) with 500 A flowing in the HLP (Fig. 9h). The corresponding voltage at the VSP and HLP are shown in Figures 9e and 9g.



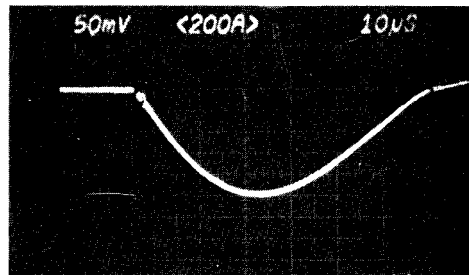
(a) open-circuit voltage



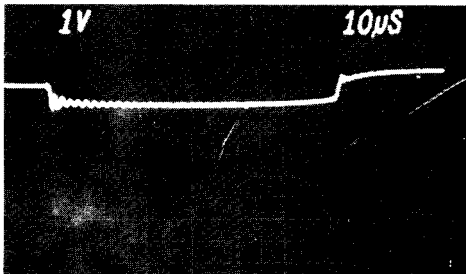
(b) short-circuit current



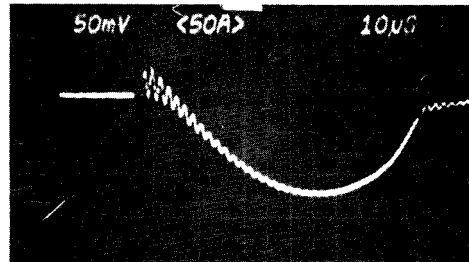
(c) VSP at 25 ft. (7.5m) - Voltage of VSP



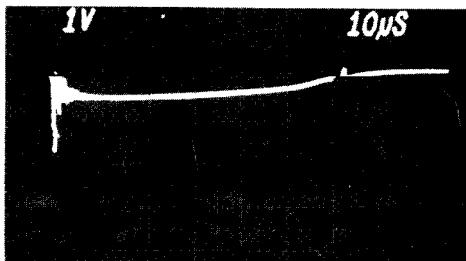
(d) VSP at 25 ft. (7.5m) - Current in VSP



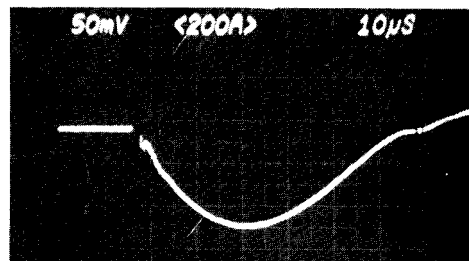
(e) VSP at 100 ft. (30m) - Voltage of VSP



(f) VSP at 100 ft. (30m) - Current in VSP



(g) VSP at 100 ft. (30m) - Voltage of HLP

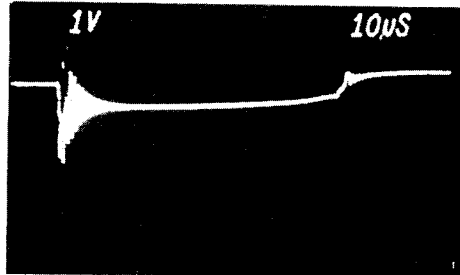


(h) VSP at 100 ft. (30m) - Current in HLP

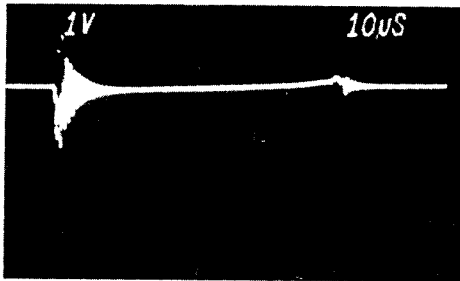
Figure 9
Transfer of Surges

Further information is presented in Figure 10, with oscillograms recorded at the same generator setting as in Figure 9. Figure 10c shows the voltage at the end of the 100 ft. (30m) line, between the line wire and the ground wire (not the ground reference, but the ground carried with the wire); likewise, Figure 10b shows the voltage at the same point between the neutral wire and the ground wire, both oscillograms recorded with the HLP at the service box and the VSP at that line end. These volt-

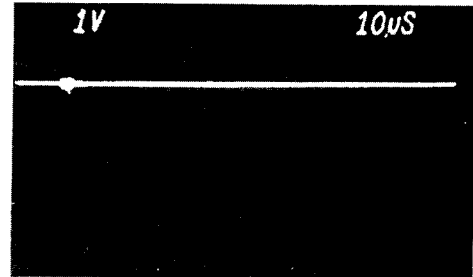
ages should be compared to the line-to-line (more precisely, line-to-neutral) voltage of only 500 V recorded for the same surge condition in Figure 9e. To check that these voltages were not spurious recording, the oscillogram of Figure 10c was recorded with the probe tip connected to its ground connection, and both of these connected to the ground wire at the 100 ft. line end. The noise background there is insignificant compared to the recordings of Figures 10a and 10b.



(a) Voltage between line (black) to ground (green) VSP connected between black and white WTP at service box.



(b) Voltage between neutral (white) to ground (green) VSP connected between black and white. HLP at service box



(c) Noise background check

Figure 10

Voltages between Conductors and Ground
at End of 100 ft. (30m) Line

VI. CONCLUSIONS

The tests on simulated high energy surges indicate that a transfer occurs from the VSP to the HLP at some current level depending on the distance between the two devices.

Even for a short length of wire, the VSP is relieved from the surge by sparkover of the HLP before excessive energy can be deposited in the varistor of the VSP. At lower current levels where the voltage in the system is clamped by the VSP and thus prevents sparkover of the HLP, the VSP absorbs all of the surge energy.

In all instances, the voltage level at the VSP is held low enough to protect all electronic appliances having a reasonable tolerance level (600 V in most cases, 1000 V in extreme cases). Furthermore, the installation of only one VSP in the house already provides substantial protection for other outlets, although optimum protection requires the use of a VSP at the most sensitive appliance, with additional VSP's if further protection is required for other sensitive appliances.

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HOME LIGHTNING PROTECTOR

D-12

5937

Page 1

Home Lightning Protector

Listed by Underwriters' Laboratories (UL)

Sept. 2, 1975
Effective Aug. 8, 1975

DESCRIPTION

The Home Lightning Protector is designed to prevent lightning surges (entering through the wiring) from damaging electrical wiring and appliances. The Protector is a sturdy, weatherproof, service-proven device that immediately drains lightning surges harmlessly to ground. Installed at either the weatherhead or service-entrance box, the Protector discharges a surge in a fraction of a second. It will perform this protective function over and over again, without any maintenance required, possessing the same long-life valve-type characteristics obtainable in higher-voltage distribution arresters.

The Protector is a two-pole, three-wire device designed primarily for single-phase 120/240-volt three-wire grounded neutral service. It can also be applied to protect three-phase circuits where the line-to-ground 60 Hertz voltage does not exceed 175 volts. Connection diagrams are included on the inside of each carton.

WHERE TO USE

Farmers—whose livelihood depends on milking machines, incubators, coolers, submersible pumps, and other electrical equipment.

Suburbanites—with considerable dependency on (and investment in) electrical appliances of all sorts.

Rural Homeowners—often far from fire-fighting equipment, and repair facilities.

Everyone—with electrical equipment exposed to the destructive lightning surges that can enter through directly-connected overhead secondary power lines.

*FEATURES

The General Electric Home Lightning Protector

- can prevent costly appliance repair
- can help provide uninterrupted electrical service
- 1-year unit replacement guarantee



PRICES AND DATA

Distribution Transformer-P(032)

Circuit Rating Volts	Protector Max Permissible Line-to-ground Voltage Rms	Protector Model No.	List Price Each, QO-75E	Net Wt Each In Oz.	Std Package
120/240 Ground Neutral	175	9L15DCB002	\$14.95	6	24 Units

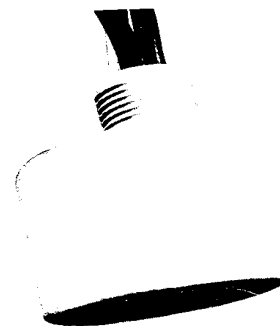
PERFORMANCE CHARACTERISTICS *

Protector Rating (Volts Rms)	Impulse Sparkover Voltage 10Kv/μsec Kv crest	IR Discharge Voltage Kv Crest (10 x 20 Microsecond Current Wave)		
		At 1500 Amp	At 5000 Amp	At 10,000 Amp
0-175	2	1.0	1.2	1.4

* Average values.

★ Changed since May 13, 1974 issue.

PM 700, 701, 702, 711-714, 721-723, 731-737

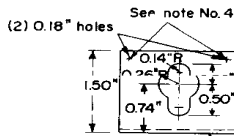


(Photo 1219173)

Fig. 1. Home Lightning Protector. Hardware (not shown) is included in carton and detailed below.

Note - Service protector may be mounted either side up - with bracket. It may be suspended by its leads or mounted in knockouts in load center or fuse boxes.

All leads are tinned copper (2) black leads No. 14 AWG (line) (1) white lead No. 14 AWG (ground)



- Included with protector
1. Aluminum mounting bracket.
 2. Aluminum screw with slotted head.
 3. Aluminum conduit locknut.
 4. An aluminum nail 1-inch long is furnished to more securely mount the arrester.

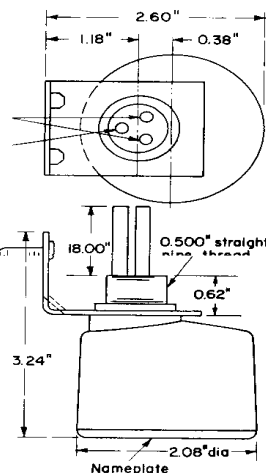


Fig. 2. Model No. 9L15CB002 Home Lightning Protector

NOTE: Minimum order quantity is one (1) standard package containing twenty-four (24) units. Orders will be accepted for shipment from factory stock in lots of one or more standard packages only. Orders for less than standard package quantities should be referred to local distributors.

PUBLICATIONS: (Use latest issue)
Descriptive Bulletin GED-4835

Prices and data subject to change without notice


GENERAL ELECTRIC

Home
Protector
Secondary
Arrester

APPENDIX II

Voltage Spike Suppressor Product Information


VSP-10




VOLTAGE SPIKE PROTECTOR

Helps protect and extend the life of solid-state electronic equipment.

15A-125V AC



GENERAL ELECTRIC



HI VI™ Plg H 233C1



VOLTAGE SPIKE PROTECTOR



VOLTAGE SPIKES are brief high voltage surges which may occur in any electrical system. They may arise from several sources, but in a home the two most common are:

- switching OFF and ON appliances, air conditioners, or furnaces within the house.
- surges on the power lines to the house caused by lightning.

MAJOR CAUSE OF ELECTRONIC EQUIPMENT FAILURE

While solid-state equipment is much more reliable than tube-type equipment, it is more susceptible to voltage spike damage. Small spikes shorten the life of solid-state components while large spikes — such as those which may occur during lightning storms — can destroy them instantly.

SIMPLE, RELIABLE PROTECTION

Plug the Protector into any 125V AC receptacle. Plug equipment into the Protector. To protect more than one piece of equipment, plug a multiple outlet adaptor into Protector.

The Voltage Spike Protector contains a GE-Mov® varistor which absorbs dangerous spikes but does not interfere with normal current flow. It is designed to protect sensitive electronic equipment from voltage spikes caused by the "switching of loads" or lightning striking the power lines. Protector will not protect against those rare circumstances where lightning strikes the house, power service takeoff, or antenna directly.

VOLTAGE SPIKE PROTECTOR HELPS PROTECT

HOME APPLIANCES

- TV Sets
- Radios
- Hi-Fi Equipment
- Electronic Organs
- Major Appliances

INDUSTRIAL/COMMERCIAL EQUIPMENT

- Computers
- Business Machines
- Industrial Controls
- Test Equipment
- Medical Equipment

Some TV manufacturers are incorporating GE-Mov® varistors in their new solid-state sets to reduce repair rates. These sets do not require added protection.

*Price optional.
See list.



Wiring Device Department
General Electric Co., Prov., R. I. 02940



GENERAL ELECTRIC

Cat. No. VSP-10